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A PORTABLE INSTRUMENTATION KIT FEASIBILITY STUDY

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13 ABSTRACT

Historically, the US Army Aviation Systems Test Activity has been involved in many limited-scope, short-reaction-time programs. In general, the test requirements did not warrant installing instrumentation. However, on most occasions some quantitative information would have greatly assisted the evaluation. The purpose of this study was to investigate the feasibility of developing an airborne instrumentation kit that could be easily transported and quickly installed. The system would need to be compatible with anticipated US Army vehicle and test requirements. Results show that a system can be developed which will meet the requirements for all but the most extensive testing. The system will also interface with existing instrumentation and data processing systems. The weight of the system is estimated to be 30 pounds with dimensions of 12 by 15 by 9 inches. The cost is expected to be approximately $90,000.

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Historically, the US Army Aviation Systems Test Activity has been involved in many limited-scope, short-reaction-time programs. In general, the test requirements did not warrant installing instrumentation. However, on most occasions some quantitative information would have greatly assisted the evaluation. The purpose of this study was to investigate the feasibility of developing an airborne instrumentation kit that could be easily transported and quickly installed. The system would need to be compatible with anticipated US Army vehicle and test requirements. Results show that a system can be developed which will meet the requirements for all but the most extensive testing. The system will also interface with existing instrumentation and data processing systems. The weight of the system is estimated to be 30 pounds with dimensions of 12 by 15 by 9 inches. The cost is expected to be approximately $90,000.

TABLE OF CONTENTS

INTRODUCTION

BACKGROUND

1. The US Army Aviation Systems Test Activity (USAASTA) has been involved in many limited-scope, short-reaction-time programs. A majority of these programs have been conducted away from Edwards Air Force Base. Typical programs are evaluations of operational aircraft following their modification to accept certain research and development subsystems, or to correct operational deficiencies and shortcomings. In general, the changes have not had sufficient effect on the aircraft to warrant installing instrumentation. However, on most occasions some quantitative information would have greatly assisted the evaluation. Development of an instrumentation package that can be transported easily and quickly installed with a minimum of expense and manhours required would greatly enhance the evaluation of future test aircraft.

2. In addition to the off-site application, the system could be used as required to supplement the standard USAASTA instrumentation capability and decrease our response time for limited programs.

STUDY OBJECTIVES

3. The objectives of this study are as follows.

a. Determine parameters that could be measured successfully with portable instrumentation.

b. Estimate cost and availability of portable instrumentation.

c. Assess usefulness of instrumentation, problems with setup, and difficulty with finding proper instrumentation location.

CHRONOLOGY

4. The chronology of the feasibility study is as follows:

Test directive received	22	May	1970
Study initiated	22	May	1970
Study completed	4	November	1971

DISCUSSION

GENERAL

5. To be useful in a wide variety of programs, a portable instrumentation kit (PIK) must be extremely versatile. Since in most instances the measurement of only one parameter is of little value, an instrumentation package should measure simultaneously those variables necessary for a meaningful evaluation. The number of variables needed depend upon the given situation, and it is, therefore, virtually impossible to design a portable recording system for universal application. However, with modern electronics, it is possible to measure a large number of parameters with a small package.

6. Through transducers or sensors, most aircraft phenomena can be reliably reduced to electrical signals, analog or digital, which are suitable for input to a modern recording system. For a portable system, restrictions will be imposed by transducer size, handling ease of transducers, transducer accuracy, system recording capability, overall system accuracy, installation limitations, pre- and post-flight requirements, package size, and package weight.

7. In addition to the acquisition and recording, careful consideration must be given to the data output and eventual data handling or analysis. A permanent paper record is needed and a magnetic tape compatible with automatic data processing systems is strongly desired.

8. A portable instrument package can vary from existing systems to a totally new system utilizing the most advanced concepts and equipment. This study is devoted to an evaluation of three selections within the possible scope. The first is a portable package using currently available oscillograph and photopanel parts. A second choice is a package made up of a group of simple mechanical transducers developed locally, and a minimum of additional electronic equipment. The third candidate is a complete electronic package utilizing state-of-the-art miniature electronics. A complete analysis of each option will provide a data basis for selecting that most suitable within the time, equipment, and money constraints.

DEFINITION OF SYSTEM REQUIREMENTS

General

9. The system requirements are determined by the parameters that must be recorded and the necessary data output. Requirements determine the sensors, recording devices, and output format. The portability feature and quantitative data scope place constraints on each element within the system.

10. A functional-flow diagram of the portable system concept is shown in figure A. The constraints that apply must be determined. They will be in the form of specifications, limits, tolerances, or any definition acceptable as a limiting quantity. The output constraints may be imposed by the effective needs of the user.

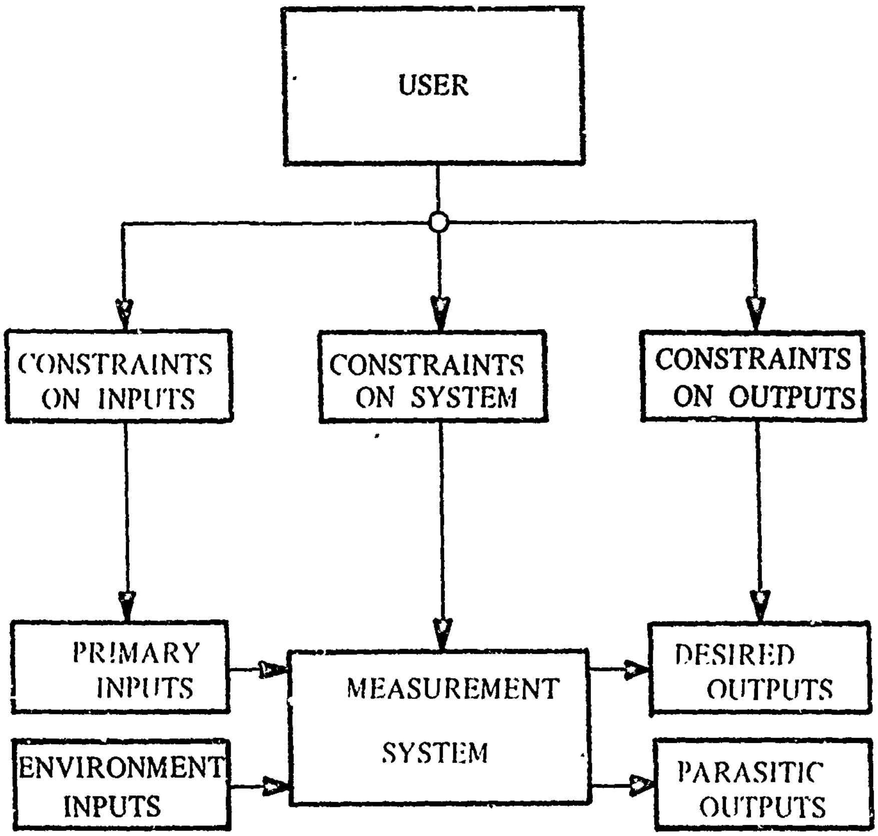

Figure A. System Concept.

11. The different kinds of inputs which the system records and transforms to outputs are aircraft characteristics and data control information. The system installation and operational requirements include:

a. Environmental (*eg*, pressure, temperature, shock, vibration, moisture).

b. Human (*eg*, effort, time, control, presence).

c. Physical (*eg*, size, weight, power).

12. The recording system will be determined by the total system inputs. Some typical systems to be considered include:

a. Hand recording from visual indicators.

b. Mechanical recording devices.

c. Oscillograph.

d. Real time telemetry trace.

e. Airborne magnetic tape system.

13. The characteristics of the system chosen will point to the most logical output medium. At this point it will suffice to state some reasonable alternatives:

a. Analog recorder.

b. Digital printer.

c. Memory oscilloscope.

d. Digital indicator.

e. Analog indicator (electric).

f. Analog indicator (mechanical).

Aircraft Data Recording Requirements

14. A list of potential data parameters was generated from instrumentation employed in previous flight test evaluations. Table 1 shows the kind of measurements common to the tests. This information regarding air and operating parameters, performance, and stability and control, coupled with requirements for vibration and stress measurements, will facilitate derivation of channel requirements for a PIK. The flight test reports investigated are identified in references 4 through 9, appendix A.

measurements common to the tests. This information regarding air and operating parameters, performance, and stability and control, coupled with requirements for vibration and stress measurements, will facilitate derivation of channel requirements for a PIK. The flight test reports investigated are identified in references 4 through 9, appendix A.

15. These reports do not necessarily define the requirements for the PIK; however, it is considered that if the PIK can monitor all the parameters listed in table 1, it will be adequate for the anticipated use.

16. The parameters as shown in table 1 were surveyed in references 4 through 9, appendix A, to determine the repetitiveness of specific requirements. The survey is included as appendix B.

Table 1. Parameters Surveyed.

Parameter	Report Number	Category
Yaw acceleration	2 and 5	
Roll acceleration	2	
Normal acceleration	1, 2, 4, 6	
Center-of-gravity normal acceleration	2, 5, 6	
Angle of attack	2, 5, 6	
Control positions	1 through 6	
Special measurements	1 through 6	Vibration/ stress
Voltage monitor, timers, event markers	1 through 6	Correlation

17. Table 2 is a summary of the parameters that a PIK should be able to measure. However, it should be remembered that virtually any aircraft measurement can be made if a transducer is supplied with the test aircraft. The table incorporates only those parameters that are considered within the scope of a self-sufficient system.

Table 2. Portable Instrumentation Kit Parameters.

Parameters	Rotary motion Temperatures (less than 75°F) Positions Forces Aircraft attitudes Aircraft rates Linear accelerations Vibration Pressure

18. In addition to recording the data, the system must have provisions to generate and record timing and event information. This is necessary to properly correlate and process the data prior to analysis.

Package Environment:

19. A PIK should operate efficiently and with design accuracy when subjected to environmental conditions within the following ranges:

a. Temperature: -30°C to +75°C.

b. Relative humidity: Zero to 100 percent at mean of temperature range.

c. Pressure altitude: -500 feet to 30,000 feet.

d. Acceleration: ±10 g's in all planes.

e. Vibration: ±1.5g peak to peak at 0 to 5 Hz
±3g peak to peak at 5 to 30 Hz
±10g peak to peak at 30 to 2500 Hz
±25g shock load.

Installation Factors:

20. For any given measurement problem, the time required to generate a test plan and select and install transducers will be essentially independent of the recording method employed. To be effective, the installation and checkout time for a recording system must be minimized.

21. To estimate the time required for the installation of the transducers, three things must be known:

a. The type of transducers to be used.

b. The type of aircraft in which they will be installed.

c. Their location in the test aircraft.

22. The intended use for this package implies that instrument installation time be minimal. Two men should be able to install and check out a basic complement of transducers and the recording package in 8 hours. At least one of the team should be well trained in use of the PIK.

Physical Restrictions

Space Limitations:

23. The size of the portable instrumentation kit will be limited by available aircraft space. Signal conditioning, recording instruments, and interfacing will have to fit into available compartments, that is, space that is accessible without taking the vehicle apart.

24. The AH-1G (HueyCobra), the OV-1D (Mohawk), and the TH-55A were found to be the existing limiting vehicles. The AH-1G has approximately 3 cubic feet of space available behind the pilot seat. The OV-1D has five compartments that are suitable for PIK installations. However, the size of the individual compartments would be the limiting factor. Dimensions of the largest camera compartment are approximately 1.5 feet by 1.5 by 2.5 feet. In the TH-55A, the PIK would be placed in the copilot seat; the available space is approximately 7 cubic feet.

25. On this basis, the maximum size of the package (or combination of components) must be at least consistent with the limitations of the AH-1G, OV-1D, and the TH-55A.

26. Beyond the aircraft's size limitations previously discussed, the system must be portable from the user's standpoint. A total system should be reducible to a small number of components, suitable for handling as carry-on baggage for two men on commercial airlines.

Availability of Power

27. All the aircraft investigated have the ability to supply at least 5000 watts to an instrument system under short transient conditions. A transient demand of 2800 watts would pose no constraint. On a continuous basis, all the vehicles can supply 1000 watts. The instrumentation systems now in use are supplied with a 980 watt capability (28 VDC at 35 amps). For the PIK, a maximum continuous energy demand of 700 watts should be specified.

Weight Limitations

28. Total weight of the PIK will not be a severe design limitation so far as the aircraft are concerned. The weight-carrying capability of each aircraft investigated is sufficient to support the oscillograph recording systems now in use. In most cases, a potential test vehicle will support a copilot which represents a maximum load of 200 pounds.

29. Instrument installation will affect the center of gravity (cg) of a test vehicle. However, it is not possible to make a quantitative investigation of the effects. Each possible case is unique insofar as the allowable aircraft cg limits. the positioning of test instrumentation, and the flight test configuration is concerned. A cg shift will be compensated for on the basis of weight and balance calculations for the given situation. Therefore, the total weight of the PIK will be as light as is practical and consistent with required information-gathering capability, desired flexibility, and size. A final weight (transducers, power supplies, signal conditioning, recording equipment) of 50 pounds is considered representative.

POSSIBLE SOLUTIONS

General

30. Previous analysis and problem definition shows that a portable instrumentation kit should represent the best compromise between the following items:

a. Ability to measure properties of required parameters and conform to specified physical restrictions.

b. Availability to fulfill immediate test needs.

c. Ability to accommodate changes in future needs.

d. Usefulness as a supplement to present test equipment.

e. Cost.

31. After a recording system or design philosophy (if nonelectrical instruments are used) has been adopted, a complement of transducers must be developed that is consistent with the PIK needs. This development should be an evolutionary process. That is, each parameter must have its associated transducer scrutinized with respect to user acceptability, ease of handling, and conformity to system constraints. Thus, the range of PIK solutions is defined by the availability of recording instruments and associated peripheral equipment.

Present Capability:

32. Three methods of data acquisition have been employed in USAASTA. The most widely used is the light-beam oscillograph (this device is described in more detail in paragraph 36. Another common device is the photopanel or a visual cockpit indicator panel. A limited portable instrumentation kit can be made with a combination of the existing equipment. One of the smaller oscillographs such as the CEC 5-114 can be used to record up to 24 parameters. In addition, a small photopanel may be constructed for additional channels or to facilitate the measurement of parameters not easily adaptable to a graphic recorder.

Mixed System:

33. A more viable solution is the assembly of a mixed group of instruments. This group would consist of a small, battery-powered, low channel capacity graphic recorder, a minimum of signal conditioning equipment, and a complement of special purpose transducers (developed inhouse) for quick installation. An example of an inhouse development is a stick plotter. This is a mechanical device which utilizes a plotting board located in close proximity to a control lever supported by means of an instrument panel. A writing implement is affixed to the control lever to allow stick motion to be traced on the plotting board. Similar mechanical devices could be developed to monitor several parameters.

34. A conglomerate system consisting of a basic electronic recorder and a variety of "hand" transducers may not fulfill all parameter requirements. A deficiency in this area can be compensated for by the purchase of individual instruments.

Integrated Portable Instrumentation Kit:

35. The third possibility is a completely integrated portable system that meets or exceeds the requirements for a PIK. Before any approach can be pursued further, available data acquisition media must be studied in detail.

Comparison of Recording Systems

General:

36. There are several recording media available for collecting flight data. The light-beam oscillograph affords a simple and straightforward flight instrumentation. The output is a permanent visible trace on paper. Data reduction must be accomplished through manual evaluation of the traces.

37. If large amounts of data are to be handled, or if small amounts of data are to be processed rapidly and accurately, the signal to be processed must be in an electrical form. With a magnetic tape recorder, storage of an electrical quantity is accomplished. While in flight, transducer outputs are fed to the tape via direct recording, frequency modulation (FM), or digital methods. The signal may be recovered on the ground by means of some electro-mechanical recording device or computer processing equipment.

38. With radio frequency transmission (telemetry), conditioned transducer outputs are transmitted to a ground station which may produce real time data displays on strip charts, record data on magnetic tape, provide direct computer analysis, or perform any combination of these functions simultaneously. Figures B through D show the basic components of each system. Table 3 tabulates the comparison of recording systems.

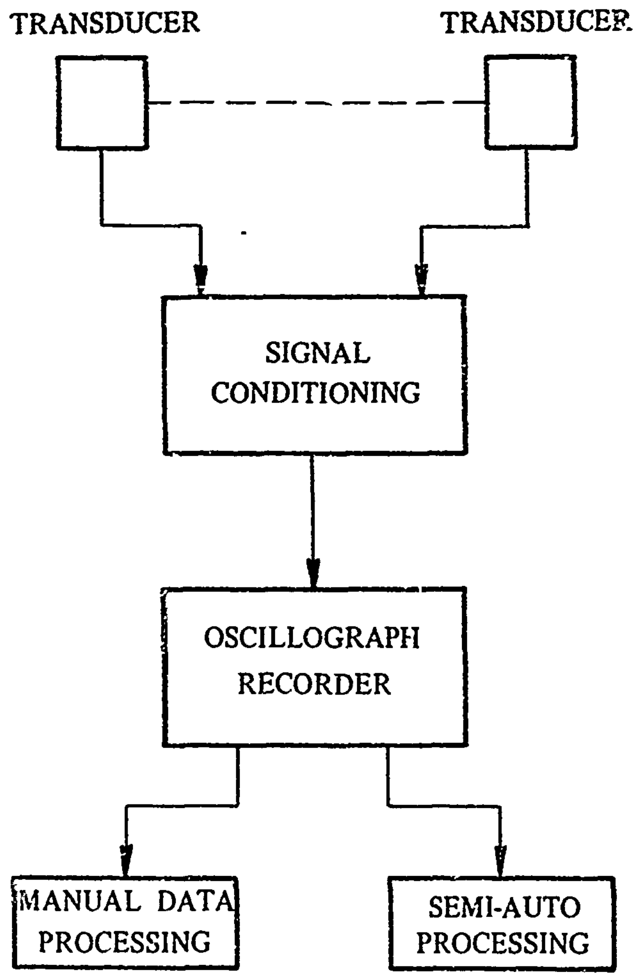

Figure B. Oscillograph Recording System.

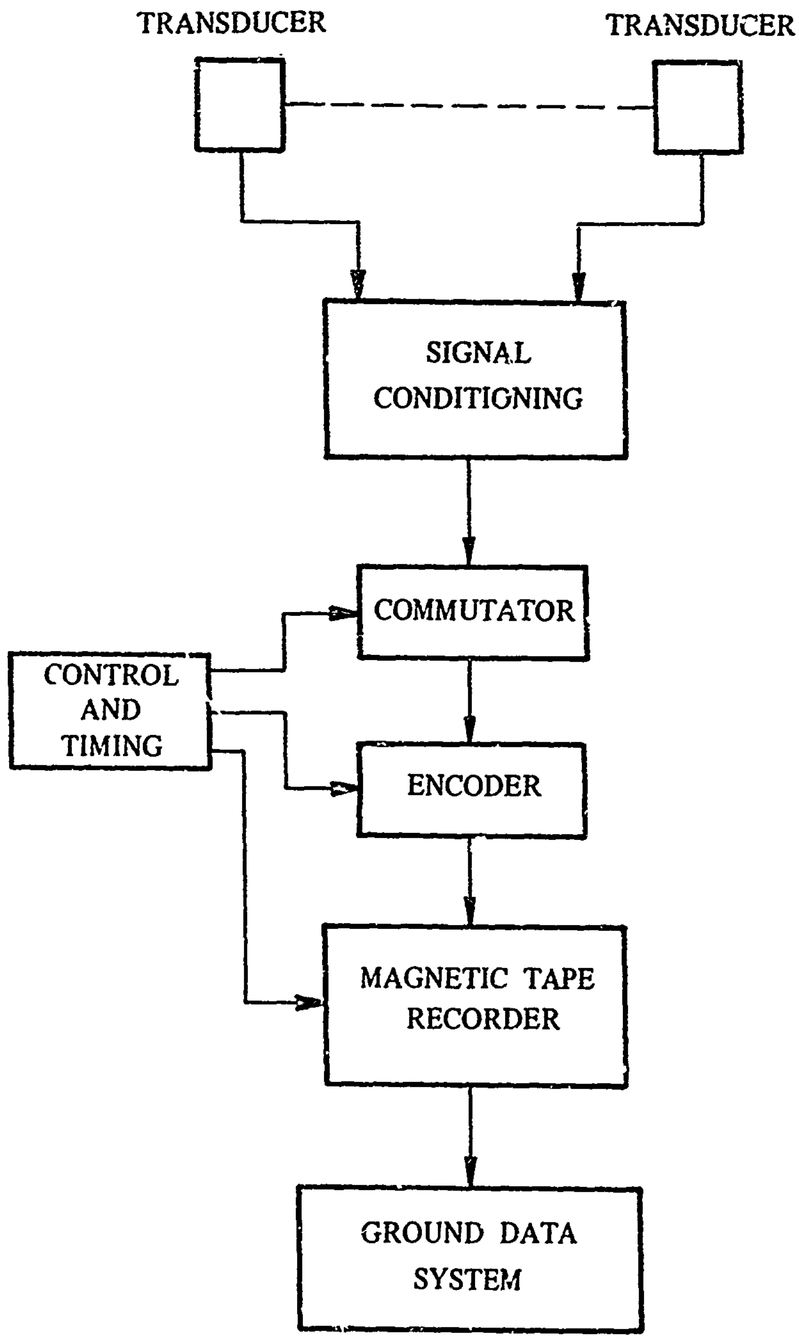

Figure C. Magnetic Tape Recording System.

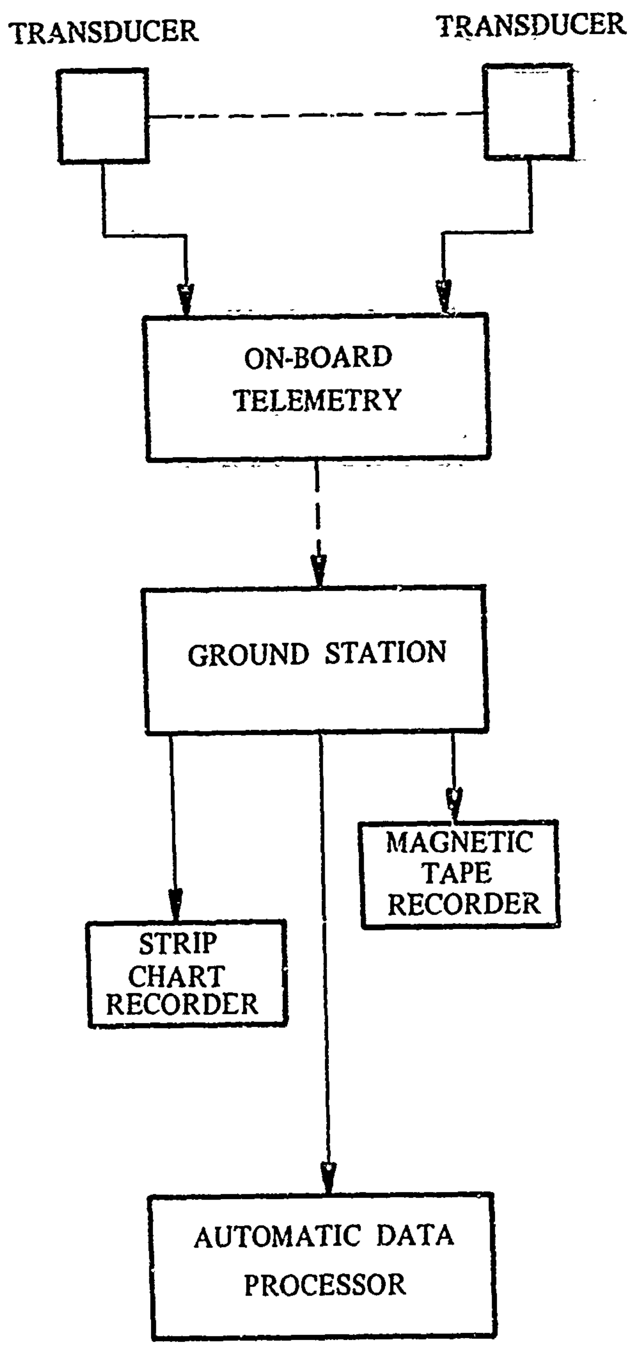

Figure D. Telemetry System.

Table 3. Comparison of Recording Systems.

Data Acquisition Comparison	Oscillograph (CEC 5-116)	Magnetic Tape Recorder (Leach Satellite Type)	Telemetry (FM-FM, PCM Systems)
Typical accuracy	±2 percent	±1 percent (digital recording accuracy is limited only by transducers and A/D converters)	FM-FM, ±1 percent; PCM, ±5 percent
Maximum information rate	1.78×10^5 bits/sec	FM, 8×10^5 bits/sec; PCM, 1.92×10^6 bits/sec	10^6 bits/sec
Data storage capacity	4.27×10^6 bits	9.98×10^7 bits	Limited by ground equipment only
Channel capacity	14 active traces	Depends on word length up to 128 data channels without subcommutation	FM-FM (UHF), ᵅbw - 21 const. bw - 21; PCM (UHF), depends on word length super and subcommutation may be used
Data processing	Difficult and involved semi-automatic readers require manual setting of each data point	Easy; automatic data processing time is reasonable	Easy; automatic data processing time is reasonable; data can be monitored by quick look
Versatility	Low; primarily readout equipment	Good; voice annotation possible	Good; voice annotation possible; quick look and simultaneous data processing possible
Guarantee of data reception	Good	Good	Not as good as for oscillograph or magnetic tape recorder
Operational Comparison	**Oscillograph (CEC 5-116)**	**Magnetic Tape Recorder (Leach Satellite Type)**	**Telemetry (FM-FM, PCM Systems)**
Installation: size weight mounts	2,100 in.^{3} 60 lb (loaded) Requires shock mounts	48 in.^{3} 4 lb No shock mounts required	Typical: 200 in.^{3} 10 lb Mountings of on-board antennas can be difficult
Preparation time for tests	Time required for matching transducers to recorder small when compared to installation time for transducers	Time required for matching transducers to recorder small when compared to installation time for transducers	Solving antenna problems can be time consumptive; otherwise, same as for oscillograph and the tape recorder
Power consumption	Typical: 300 watts at 28 VDC	8 watts at 15 ips, 28 VDC	Increases with RF power, can be large
Operation, maintenance	Easy; can be handled by semi-skilled personnel	More complicated; should be handled by trained personnel	Complex; team of experts mandatory
Equipment cost	Most simple solution; basic price about $8,000 plus $250 per galvanometer	Intermediate storage device only; graphic recorder also required; basic price about $16,000 plus $750 per channel	Minimum $8,000
Recording material cost	About 80 times the price of magnetic tape recorder with same storage capacity		

39. Each recording method requires a definite system and the choice of method depends on:

a. Ability to accomplish goals of PIK.

b. Cost.

Data Acquisition Characteristics:

40. The areas of interest in a recording system comparison can be identified by the relationship between the measurement problem and the measurement system.

a. Critical parameters that are specified by the measurement problem are:

(1) Number of data channels.

(2) Accuracy/resolution.

(3) Frequency bandwidth.

(4) Duration of measurements.

(5) Flight environment.

b. Those parameters contributed by the measurement system are:

(1) Data storage capacity.

(2) Maximum information rate.

(3) Needs of multiplex subsystems.

41. Mathematical definitions of the relationships are shown in equations 1 through 3. Let the desired amplitude accuracy of the j_{th} channel be guaranteed by use of a binary word of n bits. Shannon's sampling theorem states that if the cutoff frequency of the incoming signal is f_c, then no information is lost if the measurement system sampling rate is $> 2f_c$. Thus, the information rate of the j_{th} channel is:

$$I_j = 2f_{cj}\, n_j$$

For m channels, the total information rate is:

$$I_{total} = \sum^{m} 2f_{cj}\, n_j$$

Where: J = 1

When this is coupled with the duration of measurement (T), the required storage capacity (c) is obtained:

$$C = IT$$

Accuracy:

42. There are many effects that must be compensated for to obtain a given accuracy in a measurement system. External effects such as vibration, shock, and temperature, as well as internal effects such as zero drift, gain drift, and crosstalk must be considered.

43. Oscillograph accuracy is typically ±2 percent. An oscillograph can be affected by flight conditions. Temperature compensation is provided.

44. Direct or FM recording on magnetic tape can yield accuracies of ±2 percent. Although the visual display of tape-recorded data involves use of devices with amplitude accuracies of ±2 percent, the ground reproduction is accomplished in a better environment. Thus, the additional 2 percent uncertainty can be greatly reduced. If digital recording is used, the recording accuracy depends on the analog to digital converters which can be as good as ±0.1 percent.

45. Telemetry systems are not significantly affected during flight and in spite of medium disturbances, error can be held within ±1 percent with careful design and calibration (FM-FM). This error can be significantly reduced with digital coding (PCM).

Number of Channels:

46. The number of data channels available in an oscillograph is limited by the paper width, the number of galvanometers that can be fitted into an instrument of reasonable size, and desired resolution. Because of the problems with crossed traces the number is limited to 50 channels. However, an oscillograph with physical dimensions consistent with PIK goals can only accommodate 14-24 channels.

47. Tape recorders that could be of use in a PIK are available with 4 or 7 recording tracks. For direct recording this means that only 4 or 7 data channels are available. However, virtually unlimited channel capacity can be obtained with time or frequency multiplexing. Practically, this capacity is limited by circuit complexity and maximum information rates. For a PIK the number of required parameters should be less than 30 channels.

48. Telemetry requires multiplexing if more than 1 channel is necessary. The channel capacity with multiplex is the same as a tape recorder.

Bandwidth:

49. Oscillograph galvanometers are available with natural frequencies up to 13KHz. The effective bandwidth of an oscillograph is about 3KHz. A wideband tape recorder using FM methods will allow recording of 4 to 7 separate channels with bandwidths of 20KHz (60 ips). If digital recording methods are employed, bandwidths of 8KHz may be obtained (4 channels at 60 ips, 6 bit word). For telemetry, cutoff frequencies of 20KHz may be obtained with multiplex methods (FM-PCM).

Maximum Information Rate:

50. Equations (1) and (2) may be used to find the information rate of the jth channel. The channel capacity must at least equal this information rate. For an oscillograph using 14 traces with 1.5 percent amplitude resolution (6 bit), with time resolution of 12.7 sinewave/inch, and maximum paper speed of 100 inches/second:

$$I_o = 14 \left(\frac{5 \text{ bits}}{\text{sample}}\right)\left(\frac{2 \text{ sample}}{\text{sinewave}}\right)\left(\frac{12.7 \text{ sinewave}}{\text{inch}}\right)\left(\frac{100 \text{ inch}}{\text{sec}}\right)$$

$$= 1.78 \times 10^5 \frac{\text{bits}}{\text{sec}}$$

With a magnetic tape recorder utilizing PCM and having a packing density of 8 K bits/inch at 60 inches/second, 4 tracks give:

$$I_{TD} = 4 \left(\frac{8 \text{ K bits}}{\text{inch}}\right)\left(\frac{60 \text{ inch}}{\text{sec}}\right) = 1.92 \times 10^6 \frac{\text{bits}}{\text{sec}}$$

Magnetic tape recording wideband FM on 4 tracks at 60 inches/second yields.

$$I_{T\ FM} = \left(4 \quad 20\text{KHz}\right)\left(\frac{2 \text{ sample}}{\text{sinewave}}\right)\left(\frac{5 \text{ bits}}{\text{sample}}\right) = 8 \times 10^5 \frac{\text{bits}}{\text{sec}}$$

Therefore, the channel capacity of the miniature magnetic tape recorder is from 4.5 to 10.8 times that of the oscillograph. Telemetry methods standardized in accordance with IRIG standards have information rates that lie between the oscillograph and magnetic tape. With PCM the maximum is approximately 10^6 bits/sec.

Storage Capacity:

51. The principle of storage capacity need only be applied to oscillographic and tape recorders, since the recording of telemetry data can be accomplished by any

combination of methods. For an oscillograph, 200 feet of paper may be loaded, which at 100 inches/second yields 24 seconds of recording time. The storage capacity is:

$$C_o = I_o T_o = \left(1.78 \times 10^5 \frac{\text{bits}}{\text{sec}}\right)\left(24 \text{ sec}\right)$$
$$= 4.27 \times 10^6 \text{ bits}$$

The tape recorder allows 52 seconds of recording time at 60 inches/second. Then:

$$C_T = I_T T_T = \left(1.92 \times 10^6 \frac{\text{bits}}{\text{sec}}\right)\left(52 \text{ sec}\right)$$
$$= 9.98 \times 10^7 \text{ bits}$$

Data Processing:

52. The choice of a data acquisition system also depends on the data processing possibilities. The simplest and most tedious method of reducing graphical data is manual measurement of traces. Semiautomatic processing with manually evaluated data being digitized and written by keypunches is an improvement. These methods require the largest number of manhours to reduce the data.

53. Magnetic tape recorders provide completely automatic data processing and reduce data processing manhours. Also, due to the choice of tape speeds for recording and reproduction, frequency transformations of analog data can be obtained.

54. Telemetry provides the most versatile system. A telemetry ground station may utilize any combination of magnetic tape recording and/or real-time data processing methods. The greatest benefit in the reduction of data processing can be realized by the use of the telemetry system.

Guarantee of Data Reception:

55. Both oscillographs and magnetic tape recorders provide reliable airborne data reception (careful selection and installation presupposed). However, telemetry systems are susceptible to dropouts due to multipath propagation. This problem can be minimized by use of special delivery techniques but the hardware problems are complex. Another anomaly associated with telemetry is reflected waves. Disturbances in the RF link can arise when the path length difference between the direct wave and a reflected wave (*eg*, from mountains or buildings) is of the same magnitude as the wavelength of the modulation signal. Most of these cases can be eliminated by use of narrow beamwidth antennas.

Operational Characteristics

Installation:

56. Size, installation complexity, and weight are critical factors to a PIK. The CEC 5-118 is a 12-trace oscillograph designed for use in missiles. It weighs 11.2 pounds and occupies 200 cubic inches of space. A 50-trace oscillograph weighs 130 pounds and occupies 5620 cubic inches of space (CEC 5-119). In contrast, a 4-track Leach Corporation miniature satellite tape recorder weighs 4 pounds and has a volume of 48 cubic inches. The Ampex Model AR-700 is a 14-track recorder that weighs 48 pounds and has dimensions of 18.7 x 16.7 x 7 inches.

57. Onboard telemetry is small and light. A typical AM-FM package (14 channels) weighs approximately 10 pounds and occupies 200 cubic inches of space (discrete components). The onboard antennas can pose installation problems. They must not affect the aerodynamics of the test aircraft and, at the same time, must meet efficiency and radiation requirements.

Time for Preparation of Test:

58. In most cases the time required for planning the test, selecting transducers, and selecting appropriate signal conditioning is independent of the recording media. The time required to install even large, heavy recorders is negligible in comparison. For telemetry, however, the determination of antenna location or installation can be very tedious and time-consuming.

Operation and Maintenance:

59. Oscillograph recorders offer the simplest and the most easily understood system. The system can be operated and maintained by semiskilled personnel. Magnetic tape systems are more complicated, with calibrations and checks being required at regular intervals. Well-trained experts should be available for use of such systems. Telemetry systems are the most complicated and operation by a well-trained team is a necessary prerequisite for successful measurements.

Cost:

60. Cost is of great importance in any installation. The sensor costs will be essentially the same for any recording system and will not be discussed. Peripheral equipment and personnel costs have also been omitted.

61. Graphic recorders are the simplest. A 14-trace oscillograph is approximately $8,000. To this a galvanometer cost of about $250 per channel must be added.

62. The basic equipment of a satellite-type magnetic tape recorder costs about $16,000. A cost of approximately $750 per channel must be added for electronics. It must be remembered, however, that the magnetic tape recorder is only a storage device and some form of graphic display is required to look at the data.

63. For telemetry, a basic RF link costs at least $8,000. In most cases graphic and magnetic tape recorders must be employed. In this case, though, the recorders are less expensive because airborne qualifications are not required.

64. For recording material on an information storage basis, oscillograph paper costs about 80 times more than magnetic tape. Also, magnetic tape may be reused many times. To determine which method is most advantageous for a PIK, consider two items. First, each parameter or characteristic given in the comparison has a special significance to the PIK. To assess this significance let the importance of the i_{th} parameter be rated on a scale of 1 to 3 where:

1 = least significant

2 = moderate

3 = most significant

Then one obtains a significance vector for a PIK where:

$$s = \begin{bmatrix} s_1 \\ \vdots \\ s_i \end{bmatrix}$$

Table 4 lists each parameter and its appraised significance.

Table 4. Appraisal of Parameter Significance.

Parameter	Vector Position	Significance[1]
Typical accuracy	s_1	2
Maximum information rate	s_2	2
Data storage capacity	s_3	1
Channel capacity	s_4	2
Data processing	s_5	2
Versatility	s_6	3
Guarantee of data reception	s_7	2
Guarantee of data installation	s_8	3
Time for preparation of tests	s_9	2
Power consumption	s_{10}	1
Operation and maintenance cost	s_{11}	1
	s_{12}	3

[1]Significance Scale:
1 = least significant.
2 = moderate significance.
3 = most significant.

Next, consider the performance of each recording method with respect to the goals of a PIK. Again using a scale of 1 to 3 where:

1 = poor

2 = good

3 = excellent

A matrix of performance coefficients is defined:

$$P = \text{Performance} \begin{array}{c} \text{Method} \\ \begin{bmatrix} P_{11} & \cdots\cdots & P_{1j} \\ \vdots & & \\ P_{i1} & & \end{bmatrix} \end{array}$$

For each recording method; table 5 lists the parameters of comparison and their associated performance coefficients.

Finally an acceptability number for use of recording systems in a PIK on a 1 to 3 scale where:

1 = least acceptable

2 = satisfactory

3 = preferred

is obtained by the relation:

$$\text{Acceptability (A)} = \frac{1}{36} P^T S$$

From table 4 the significance vector is:

$$S = \begin{bmatrix} 2 \\ 2 \\ 1 \\ 2 \\ 2 \\ 3 \\ 2 \\ 3 \\ 2 \\ 1 \\ 1 \\ 3 \end{bmatrix}$$

From table 5 the performance coefficient matrix is:

$$P = \begin{bmatrix} 1 & 3 & 3 \\ 1 & 3 & 2 \\ 2 & 3 & 3 \\ 2 & 3 & 3 \\ 1 & 2 & 3 \\ 2 & 3 & 3 \\ 3 & 3 & 2 \\ 1 & 2 & 1 \\ 3 & 3 & 2 \\ 1 & 3 & 3 \\ 3 & 2 & 1 \\ 3 & 2 & 2 \end{bmatrix}$$

Then:

$$A = \frac{1}{36} P^T S = \frac{1}{36} \begin{bmatrix} 1 & 1 & 2 & 2 & 1 & 2 & 3 & 1 & 3 & 1 & 2 & 2 \\ 3 & 3 & 3 & 3 & 2 & 3 & 3 & 2 & 3 & 3 & 2 & 2 \\ 3 & 2 & 3 & 3 & 3 & 3 & 2 & 1 & 2 & 3 & 1 & 2 \end{bmatrix} \begin{bmatrix} 2 \\ 2 \\ 1 \\ 2 \\ 2 \\ 3 \\ 2 \\ 3 \\ 2 \\ 1 \\ 1 \\ 3 \end{bmatrix}$$

$$= \begin{bmatrix} 1.28 & \text{oscillograph} \\ 1.75 & \text{magnetic tape} \\ 1.53 & \text{telemetry} \end{bmatrix}$$

Thus, analysis indicates that a magnetic tape recorder is best suited to a PIK's needs. From this point then, only magnetic tape systems are considered.

Table 5. Performance Coefficients.

Parameter	Oscillo-graph	Magnetic Tape	Telemetry
Typical accuracy	1	3	3
Maximum information rate	1	3	2
Data storage capacity	2	3	3
Channel capacity	2	3	3
Data processing	1	2	3
Versatility	2	3	3
Guarantee of data reception	3	3	2
Guarantee of data installation	1	2	1
Time for preparation of tests	3	3	2
Power consumption	1	3	3
Operation and maintenance	3	2	1
Cost	3	2	2

Integrated Portable Instrumentation Kit:

65. Figures E and F are functional block diagrams of the proposed system. The signal conditioning circuitry will serve to standardize all transducer outputs and make them compatible with the encoder inputs (zero to 5 VDC). Due to the size limitations of a portable kit, it would be advantageous to use a time-shared signal conditioner. However, because of the diversity of transducers the unit will encounter, this approach is not feasible. Therefore, each channel will be provided with an individual signal conditioning card tailored to the specific transducer. The card will provide excitation, scaling, amplification (when necessary), and bandwidth limiting (filtering).

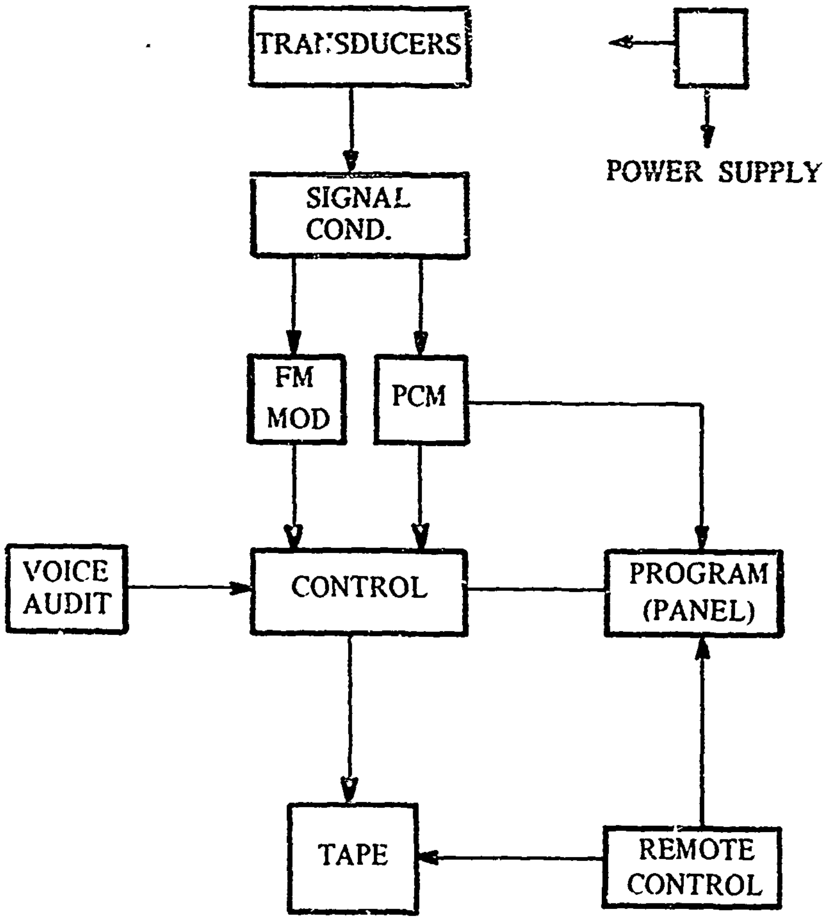

Figure E. Proposed System - Recording Section.

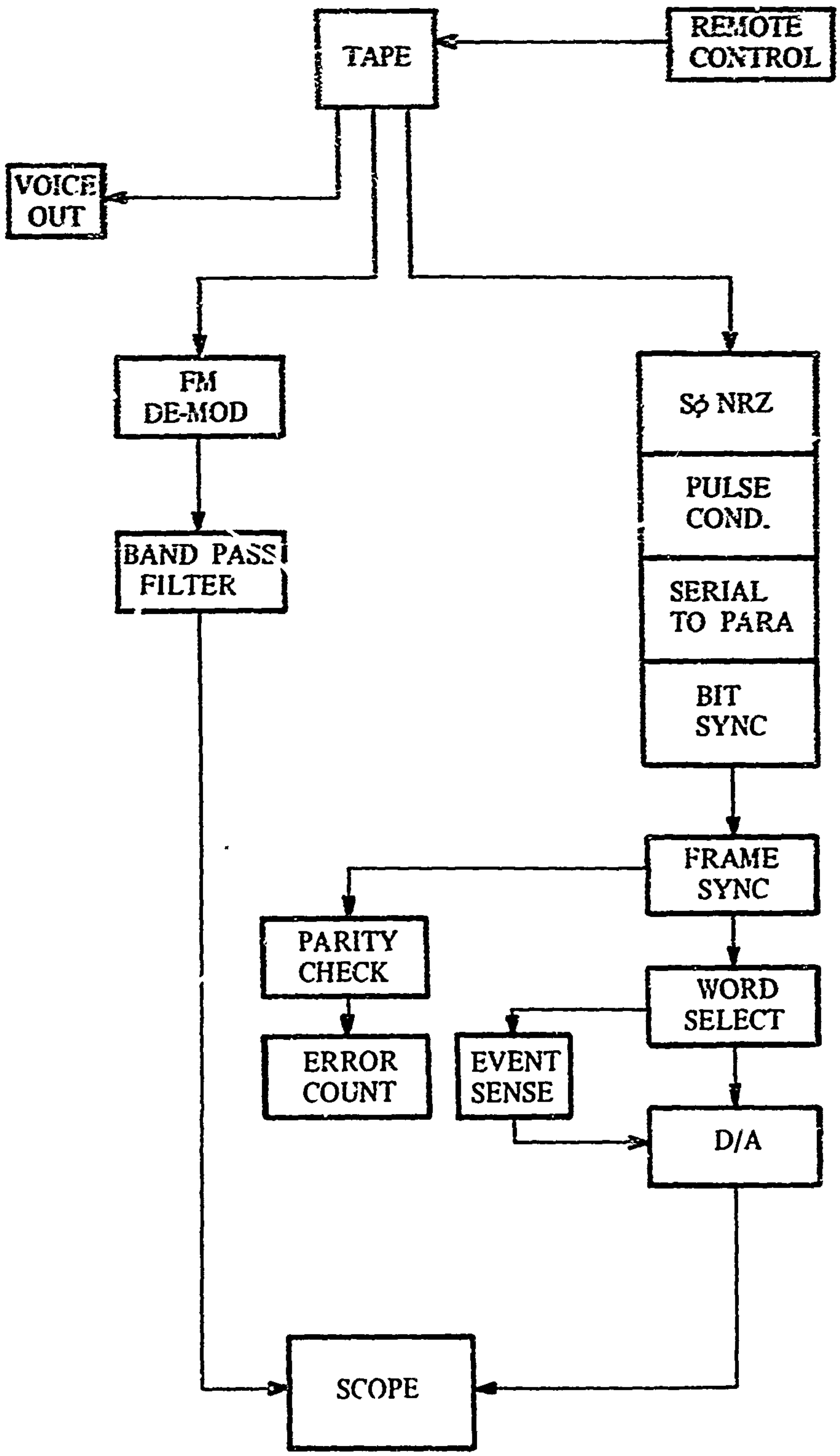

Figure F. Proposed System - Replay Section.

66. The block marked PCM encompasses many functions. The unit includes analog multiplexing, digital multiplexing, analog to digital conversion, hard-wired program control/programming, and format accumulation/output formatting. For this discussion it is only important to know that the PCM inputs are parallel analog signals, preconverted digital inputs (from asynchronous digital transducers), and event information. The output is a serial bit stream containing the input information in time-multiplexed, pulse coded form. Sampling rates will be chosen to allow coding of signals with channel bandwidths of up to 150 Hz (minimum of 5 samples/cycle). Certain parameters such as vibration or stress will often require bandwidths larger than 150 Hz. Therefore, 2 channels will be provided with a bandwidth of up to 10 KHz. This will be done via wideband FM. It is the most straightforward method of reliably recording these high frequency transducer outputs.

67. Voice, PCM, and FM information will be recorded on a miniature magnetic tape recorder. The recorder will be of the same class as those used in satellites and rockets, the actual recording commands being handled with a remote control unit.

68. Reconstruction of analog signals from the recorded PCM data requires several operations:

a. Split phase (Φ-NRZ) conversion.

b. Serial to parallel conversion.

c. Bit synchronization.

d. Frame synchronization.

e. Parity checks.

f. Digital to analog conversion.

69. To minimize size, the reconstruction of analog signals should be in the most rudimentary form. That is, the entire unit would be committed to one frame format, one or two sampling rates, one frame synchronization pattern, and only one word-form would be used. Any recording format or sampling options would be switch-selected from the hard-wired panel programmer/controller. All necessary timing and control signals would be derived from the recorded bit stream during playback.

70. The digital to analog converter output would be buffered and this buffered output level would represent the reconstructed analog input. No further processing of the signal is required. Specifically, no filtering (curve smoothing) would be necessary before application of the signal to a display device because of the sampling rate used.

71. Reproduction of the FM signals is much simpler and requires only an FM discriminator. The demodulated analog signal will also be buffered for recorder driving. One more operation needs consideration with the FM data. Since this data will usually represent vibration or stress/strain phenomena, the real information lies not in the raw time history of acceleration, but rather in the power spectral density of the signal. Obviously, one cannot hope to incorporate a spectrum or wave analyzer in a portable instrumentation kit. With a little work, however, the information can be extracted from the reconstructed signal by the use of a tunable, variable bandwidth, bandpass filter. By inserting this filter between the demodulator output and the data display device, one can isolate discrete frequency components and their relative magnitudes.

72. The ground package (fig. F) is designed to satisfy the data display, ground checkout, troubleshooting, and calibration requirements. There is a unit on the market that can satisfy all of these requirements, and in a form that makes it effectively the only candidate for use: the Tektronics Model 7514 memory oscilloscope. Two channels of data can be read into the "memory" and held as long as 1 hour for direct analysis or photographic processing of the traces. With the appropriate scaling scheme in the replay section, these traces can be read directly in engineering units. Practically speaking, as much as 5 seconds of flight data may be presented on the face with adequate resolution. Digital multimeter and eput metering plug-ins are available, making this scope a complete checkout and setup instrument for quick evaluations. With a well-planned system of test points and prepared harnesses, the unit makes the setup and checkout of the airborne section a relatively simple matter.

DISCUSSION OF SOLUTIONS

Present Capability

73. The instruments currently available at USAASTA are not representative of those which can provide portable instrumentation. The recording equipment is too heavy and bulky for mobile use, and power consumption is excessive. Each channel of information requires an excitation source, some form of signal conditioning (for standardization, balancing, amplification, range switching, etc.), and interconnecting cable between power source and excitation source, between power source and recorder, between transducer and signal conditioner, and, finally, between the signal conditioner and the recorder. This type of installation and the man-hours required for setup is not a practical solution.

Mixed System

74. The combination of a small Visi-corder with instruments and a variety of mechanical measuring devices offers an improvement. One virtue of this approach is that, with careful selection of components, the transducers and their associated apparatus will be compact and easy to use (assuming less than about four simultaneous measurements). A transducer/recorder interface is still required. This third unit would supply the necessary signal conditioning functions, supply

transducer excitation, and generally serve as the control unit. If a larger number of channels are to be monitored, the setup will become ungainly and suffer all the anomalies associated with a pa made up of existing equipment.

75. The mixed-system approach does not provide built-in calibration and checkout capability. Therefore, a versatile test instrument such as a digital multimeter is required. One other major problem is that small Visi-corders require shock mounts. This increases installation time and creates possible restrictions on mounting locations.

76. One favorable aspect is cost. A recorder, digital test equipment, and a small complement of transducers can be purchased for about $15,000.

Portable Instrumentation Kit

77. The system diagrams (figs. E and F) imply that a self-sufficient PIK must implement many functional services. Careful design and selection of components would result in a package whose subsystems are either suitable for use with the AIDAS or suitable for use as valuable complements to existing laboratory test equipment. In either case, it is possible to construct a portable instrumentation kit that will be of great value when used for its intended purpose or when used in carrying out normal test functions within USAASTA.

Capability and Characteristics:

78. The PIK described can accommodate:

a. Channel capacity:

(1) 10-20 analog PCM channels.

(2) 1-4 preconverted digital PCM words.

(3) Two wideband FM channels.

b. Recording time (maximum):

(1) Seven tracks used on PCM data; 210 minutes at 15 ips.

(2) One track with PCM, 2 tracks with FM; 30 minutes at 15 ips.

c. Accuracy capability:

(1) PCM - ±1 percent (overall with use of oscilloscope).

(2) FM - 5 percent overall.

d. Size (transducers excluded):

(1) Airborne; 1 cubic foot.

(2) Ground; 2 cubic feet.

e. Weight (transducers excluded):

(1) Airborne; 30 pounds.

(2) Ground; 70 pounds.

f. Power requirement:

(1) Airborne; 28 VDC/115 VAC, 50-400 Hz.

(2) Ground; 115 VAC, 50-60 Hz.

79. While in transit, the total PIK would consist of three cases. The first two would be in the form of large attache cases, one being the airborne package, and the other carrying transducers and wiring. The third case would contain the oscilloscope and the prepared probe harnesses.

80. In use, the airborne unit would not require shock mounts (assuming rugged construction) and could be mounted in any position. Input scaling and recording setup can be designed to take no more than 2 hours with a maximum capacity number of measurements.

81. Initial data would not include the tedium of measuring trace deflections and plotting data points. Time histories and parameter versus parameter plots can be generated at will on the scope face by replaying the data tapes.

Cost:

82. The cost of the true PIK described has been approximated at:

Tape recorder and electronics	$22,000
PCM encoder	14,000
Design and implementation of miniaturized circuitry	27,000
Oscilloscope and plug-ins	10,000
Components for buildup of transducer signal conditioning cards	17,000
Approximate total:	$90,000

83. At first glance, the approximate total may seem out of order for a portable instrumentation kit. However, several factors should be taken into consideration. First, it is planned to make the tape recorder and PCM units suitable substitutes for those units used in AIDAS. Such replacements will be purchased anyway. Also, a memory-type oscilloscope would be a logical addition to USAASTA laboratory equipment and would be consistent with USAASTA expansion of instrumentation capability. Thus, it is considered that the miniaturized circuitry and the signal conditioning circuitry would be the only investments committed to the PIK. These subsystems constitute $43,000 of the estimated cost. This is considered a modest cost for a package with capability second to none in the instrumentation field.

CONCLUSIONS

84. Aircraft data requirements cannot be subjected to precise definition. A survey of airborne transducers has provided enough information for analysis of the portable system problem (para 15).

a. Environmental, installation, and physical package requirements have been isolated with enough precision to facilitate analysis of the portable system problem (para 29).

b. The choice of system configuration, *ie*, the record and reproduce media, is essentially independent of parameter measurement requirements (para 20).

c. Analysis has shown that the goals of a PIK as defined can best be achieved by a system utilizing magnetic tape recording (para 64).

d. Analysis of appropriate instrument markets and common instrument systems has demonstrated technical feasibility of the proposed PIK (para 64).

85. Subjective analysis has shown construction of the proposed PIK to be an economically sound endeavor (para 83).

RECOMMENDATIONS

86. It is recommended that a detail design specification be developed for the portable instrumentation kit.

87. Upon acceptance of the design and specification, it is recommended that the proposed kit be fabricated.

APPENDIX A. REFERENCES

1. Textbook, *Modulation, Noise, and Spectral Analysis*, Philip F. Panter, McGraw-Hill Publishing Company, New York, 1965.

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3. Textbook, *D.C. Amplifiers in Instrumentation,* Ralph Morrison, John Wiley & Sons, Inc., New York, 1970

4. Final Report, USAASTA, Project No. 67-09, *Engineering Flight Test of the UH-1C Helicopter Equipped With the XM-30 Weapon System*, November 1967.

5. Final Report, USAASTA, Project Nos. 65-12 and 66-09, *Engineering Flight Test of the UH-1C Helicopter Equipped With the M-5 Grenade Launcher and the XM-158 or XM-159 Airborne Rocket Launcher Pods Suspended from the XM-156 Multiarmament Mount*, February 1967.

6. Final Report, USAASTA, Project No. 66-23, *Airworthiness and Qualification Test (Phase D) CH-47B Helicopter*, March 1970.

7. Final Report, USAASTA, Project No. 69-09, *5.56/7.62 Comparative Evaluation, OH-6A Helicopter*, June 1971.

8. Final Report, USAASTA, Project No. 65-22, *Engineering Flight Test of the UH-1B Helicopter Equipped With XM-47 Antipersonnel Mine Dispensing Subsystem*, November 1966.

9. Final Report, USAASTA, Project No. 68-43, *Army Preliminary Evaluction Preproduction OV-1D (Mohawk)*, March 1970.

10. Paper, "IRIG Telemetry Standards," R. Stanton Reynolds, Sandia Corporation, Albuquerque, New Mexico, presented at 30th Meeting of the AGARD Flight Mechanics Panel, 30 May - 1 June 1967.

11. Technical Note, "Requirements for Strain Gage Capability - Portable Instrument Kit," Joe McKinley, unpublished.

12. 1970 Catalog, *Tektronics Products*, Tektronics, Inc., Oregon, 1970.

APPENDIX B. RESULTS OF PARAMETER REQUIREMENTS SURVEY

1. The parameters were surveyed with respect to the unique PIK requirements and constraints. In the survey each parameter was evaluated in accordance with the following:

a. The purpose for the measurement.

b. Total accuracy/resolution required.

c. Transducers and methods available to make the measurement.

d. Anomalies commonly associated with the measurement.

e. If the required signal conditioning circuitry is within the scope of portable instrumentation.

f. If the weight and size of transducers is prohibitive.

g. If the installation requirements are prohibitive.

h. If suitable equipment is available for calibration, maintenance, installation, and checkout.

i. Successful monitoring of parameter in conjunction with a portable instrumentation kit.

2. The survey is presented as table A.

Table A. Results of Parameter Requirements Survey.

Parameter	Factor	Answer			Comments
		Yes	No	Accuracy	
Airspeed	a				The purpose is to determine the airspeed relative to the surrounding air mass.
	b			±0.8%	
	c				1. Aircraft standard system. 2. Test swivel head pitot-static system. 3. Aeroflex true airspeed vector system.
	d				Rotor downwash, unreadable at low dynamic pressures. Angle of attack and sideslip effects.
	e	X			
	f		X		
	g	X			
	h		X		
	i		X		
Altitude	a				The purpose is to record static pressure and/or aircraft height above sea level.
	b			±2% full scale	
	c				1. Production altimeter. 2. YAPS head. 3. Radar.
	d				Production systems may be degraded by downwash, ambient temperature, barometric pressure.
					YAPS heads suffer from same anomalies.
					Radar altimeters investigated to date do not meet requirements of b.
	e	X			
	f		X		
	g	X			Plumbing must be provided for pressure transducers.
					Leak tests must be performed.
					Trained experts required for radar installations.
	h	X			
	i		X		

Parameter	Factor	Answer			Comments
		Yes	No	Accuracy	
Rotary motion (rpm)	a				The purpose is to obtain a signal that represents the angular velocity of a rotating shaft.
	b			±0.3% full scale	
	c	X			1. Pulse rate integrator. 2. Tachometer generators. 3. Magnetic pickups. 4. Shaft angle encoders.
	d				1. None. 2. Poor resolution and hard to interface with. 3. Poor resolution. 4. None.
	e	X			
	f		X		
	g		X		
	h	X			
	i	X			
Torque	a				The purpose is to monitor power trans- mitted by a rotating shaft, *eg*, engine torque.
	b			±3% full scale	
	c	X			1. Aircraft production torquemeters. 2. Strain gages with miniature RF link.
	d				1. Sensitive to wear, vibration, and temperature. Lag times due to fluid forces unknown. 2. Untested. 3. No.
	e	X			
	f		X		
	g		X		Yes. These systems are used as an integral part of the parts being tested (committed application).
	h		X		
	i		X		
Gas producer speed					See rotary motion.
Fuel flow rate fuel consumed	a				The purpose is to provide a signal that represents volumetric flow rate and/or fluid consumed.
	b			±2% of rate ±0.5% full scale total	

Parameter	Factor	Answer			Comments
		Yes	No	Accuracy	
Pitch, roll, yaw attitudes	a				The purpose is to determine aircraft attitude with respect to an inertial reference frame.
	b			±2°	All axes.
	c	X			1. Free gyros.
					2. Caged gyros.
					3. Inertial platforms.
	d				1. Accumulative error can be excessive.
					2. Data record must be kept short during maneuvers to prevent excessive precession error.
					3. Untested in helicopter applications.
	e	X			
	f		X		
	g		X		
	h	X			
	i	X			
Pitch, roll, yaw rates	a				The purpose is to record the angular velocity of an aircraft with respect to its reference planes.
	b			±2% full scale	
	c	X			Rate gyros (three-axis sensor).
	d				The rate axes must be mutually orthogonal.
	e	X			
	f		X		
	g		X		
	h	X			
	i	X			
Vibration acceleration	i	X			See reference 11, appendix A.

Parameter	Factor	Answer			Comments
		Yes	No	Accuracy	
Pitch, roll, yaw attitudes	a				The purpose is to determine aircraft attitude with respect to an inertial reference frame.
	b			±2°	All axes.
	c	X			1. Free gyros.
					2. Caged gyros.
					3. Inertial platforms.
	d				1. Accumulative error can be excessive.
					2. Data record must be kept short during maneuvers to prevent excessive precession error.
					3. Untested in helicopter applications.
	e	X			
	f		X		
	g		X		
	h	X			
	i	X			
Pitch, roll, yaw rates	a				The purpose is to record the angular velocity of an aircraft with respect to its reference planes.
	b			±2% full scale	
	c	X			Rate gyros (three-axis sensor).
	d				The rate axes must be mutually orthogonal.
	e	X			
	f		X		
	g		X		
	h	X			
	i	X			
Vibration acceleration	i	X			See reference 11, appendix A.